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EROSION BEHAVIOR AND CONTROL ON A STRIPMINED LATOSOLIC SOIL

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LAND-GRANT COLLEGES

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RECOMMENDATIONS

(1) Stripmined soil should be graded to even slopes, preferably not exceeding 5 percent. An abrupt change in slope leads to channeling of surface runoff and consequent gullying of the soil.

(2) Subsoil exposed after stripmining should immediately be scarified by plowing, discing, or rotary-hoeing, to offset compaction in the surface few inches of soil induced by the use of heavy equipment.

(3) Surface drainage should be provided for immediately after the stripping and grading have been completed by dug, wide and shallow, semicircular surface drains, laid on a grade of approximately 4 percent. Six-inch boiler pipe (or equivalent pipe) can conveniently be used as culverts to cross access roads. Discharge of runoff water should be on naturally vegetated valley slopes only.

(4) Bagasse applications can be made under certain conditions to quickly combat an erosion hazard. Bagasse is probably effective when applied in patches, allowing simultaneous establishment of a vegetative cover. No general reliance should be placed on bagasse for erosion control, as bagasse is not available at all times and is cumbersome in handling because of its bulkiness.

(5) Various types of re-established vegetative covers are efficient for erosion control, provided they give adequate soil cover. The establishment of vegetative cover requires heavy fertilizer applications and, for quick control, a combination of quickly and slower establishing plant cover.

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EROSION BEHAVIOR AND CONTROL ON A STRIPMINED LATOSOLIC SOIL

Bessel D. van't Woudt and Goro Uehara

INTRODUCTION

Bauxite is an aluminum-rich end product of soil weathering under certain conditions of favorable drainage in tropical regions. The ore is thus concentrated at the surface and its mining entails stripping the soil for some depth. Any stripmining brings with it a danger of devaluating the land by exposing subsoil and compacting its surface.

Prior to mining, methods of restoration of the exposed subsoil should thus be studied. This possibility of land devaluation and of erosion was envisaged a few years ago when exploitation of the bauxite deposits in Hawaii (described by Sherman, 1958) came to be considered. The Hawaii Legislature made it the responsibility of the Hawaii Agricultural Experiment Station to evaluate the impact of possible stripmining on agriculture. This included an assessment of the extent to which soil erosion might occur after stripmining particular areas and what measures could be taken to prevent any serious erosion and its effect on the local watershed hydrology.

To this end, experimental work was started on the island of Kauai on a site which appeared promising as a first area to be mined. The area selected is approximately 4 miles inland from the mouth of the Wailua River in the Wailua Game Reserve area at approximately 500 feet above sea level.

Bauxite is concentrated here at the top of a number of parallel ridges, 50 to 300 feet wide, running in direction from the central mountain core of the island to the sea.

The valleys separating the ridges contain very small streams, several of which flow after heavy rain only. In an undisturbed state the area is well protected from erosion by native vegetation, consisting of grasses, ferns, and shrubs (Moomaw and Takahashi, 1960).

The depth of the economically exploitable ore deposit on the experimental site selected is approximately 15 feet at the center of the ridges, thinning off towards the edges. This approximate depth of soil was removed by

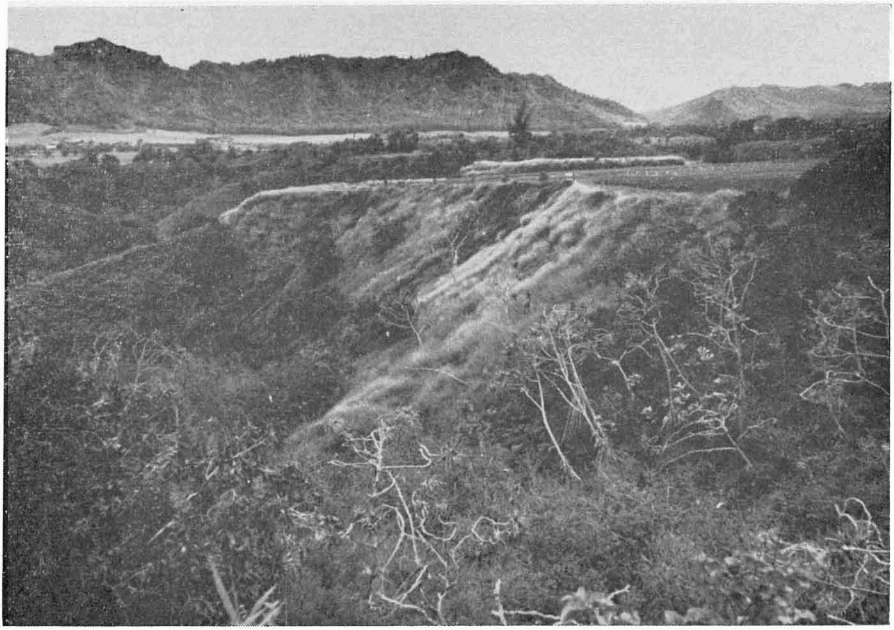


FIG. 1. The stripped ore was pushed by bulldozer onto the slopes of adjacent valleys, creating a severe test of the erodibility of the soil.

bulldozing, pushing the soil over the edge of the ridges onto the slope of adjacent valleys (figure 1). Ultimate slopes were of about the same degree as the original ones, varying from 20 to 30 degrees.

SOIL DESCRIPTION

After the stripping of approximately 2½ acres, a subsoil was left behind with favorable physical properties, a soil which is readily tillable, of a relatively stable structure, and with reasonably satisfactory infiltration rates.

The soil is a clay, as the clay content is in excess of the limits set up for definition (in excess of 50 to 60 percent clay—Lyon, *et al.*, 1950, p. 55). In Hawaii, it has been customary to classify soils on apparent texture because of the general stable micro-aggregation of clay into particles of silt size. For that reason, the soil has been described below as a silty clay. However, it should be pointed out that gravel inclusions due to gibbsite nodules vary with depth below the surface. At some depth the soil should undoubtedly be classified with the prefix "gravelly." Some of the soil properties have been discussed by Holmes, *et al.* (1960); others are discussed below.

Soil on the experimental site belongs to the Kapaa series, a deep, well-drained aluminous Humic Ferruginous Latosol developed from rocks of the Koloa volcanic series on gently sloping to steep uplands. The lavas of the Koloa volcano series consist principally of olivine basalt, nepheline basalt, melilite-nepheline basalt, and picrite-basalt of the mimosite type (Macdonald, *et al.*, 1960). Thin sample sections of a fresh rock core from the experimental site contained approximately 15 percent feldspar and many subhedral grains of monoclinic pyroxene, and some olivine and magnetite. The parent rock is probably a picrite basalt of a mimosite type.

Soils of the Kapaa series usually occur on the lower mountain slopes in a belt roughly between 200 and 1000 feet elevation with a mean annual rainfall from 60 to 100 inches. The series is bounded on the upper limits by the Halii and on the lower limits by the Puhi series. All three soils belong to the Humic Ferruginous group but the Puhi and Halii series are somewhat more ferruginous than the Kapaa series.

A profile description taken from a pit 500 feet west of the bauxite reclamation site, illustrating the major features of the Kapaa soil, is given in table 1.

At depths greater than 6 feet the variation in soil properties is too great to be useful in a profile description. The degree of weathering of the parent rock ranges from fresh rock cores to secondary clay and oxides; the structure ranges from weakly to moderately developed; and the color ranges from yellow to red. The oxide clay (gibbsite) content decreases with depth below the surface, and the content of silicate clay (halloysite) increases in that direction, but owing to leaching along any plane, considerable variation can be observed.

In general, soil structure is strongly developed at the surface and is moderately to weakly developed in lower horizons. In the surface soil, iron and aluminum oxides and organic matter have given rise to a large fraction of aggregates of a moderate size of substantial stability.

CLIMATIC DATA

No detailed climatic data for the area were available. The climatic measurements made during the period of experimentation are thus presented here as a background to this study.

The taking of climatic data has been confined to measuring rainfall and evaporation. A recording rain gage was installed at the site of erosion measurement and a standard United States Weather Bureau (U.S.W.B.) rain gage was placed approximately 1000 feet away. Approximate evaporation was measured by a recording evaporation pan reported on by van't Woudt (1960).

The data from the recording and the U.S.W.B. rain gage show substantial daily variation, apparently due to the passage of isolated, small rain clouds and to some local rain-shadow effects. However, the total rainfall from both gages runs parallel.

TABLE 1. Description of Kapaa Soil Series*

HORIZON	DEPTH, INCHES	DESCRIPTION
A1	0–7	Horizon 5 to 8 inches thick with abrupt, smooth lower boundary. Dark-brown (10YR 3/3) silty clay loam, dark brown (10YR 4/3) when dry; strong, very fine, fine and medium granular structure; sticky, very plastic, firm; many roots; many fine and medium interstitial pores; fine secondary oxide aggregates few to common.
B2.1	8–14	Horizon 5 to 9 inches thick with clear, wavy lower boundary. Dark reddish-brown (5YR 3/4) silty clay loam; weak coarse subangular blocky structure; sticky, plastic, firm; roots common; many very fine and fine pores and few coarse pores; numerous worm casts with fillings of 10YR hue; few thin patchy glazed coatings on ped surfaces; few pebble-sized oxide fragments.†
B2.2	15–19	Horizon 3 to 9 inches thick with clear, wavy lower boundary. Reddish-brown (5YR 4/4) silty clay; weak medium subangular blocky breaking to weak very fine subangular blocky structure; sticky, very plastic, firm; roots common; many very fine and fine pores; nearly continuous glaze on ped surfaces; few to common pebble-sized oxide fragments; very fine yellowish-brown (10YR 5/6) gibbsite particles.
B2.3	20–28	Horizon 6 to 13 inches thick with clear, wavy lower boundary. Dark reddish-brown (2.5YR 3/4) silty clay, with many coarse mottles of strong brown and yellowish red; moderate very fine and fine subangular blocky structure; sticky, very plastic, friable; few roots; many fine and very fine pores; numerous very fine hard earthy lumps that are probably gibbsite; nearly continuous glaze on ped surfaces.
B2.4	29–42	Horizon 9 to 16 inches thick with clear, wavy lower boundary. Dark reddish-brown (5YR 3/3) silty clay; moderate very fine and fine subangular blocky structure; sticky, very plastic, firm; few roots; many fine and very fine pores; many oxide fragments; many fine hard earthy lumps that are probably gibbsite; continuous glaze coating on ped surfaces, thicker than in above horizon.
B2.5	43–52	Horizon 3 to 13 inches thick with abrupt lower boundary. Dark-red (2.5YR 3/6) silty clay; moderate very fine and fine subangular blocky structure with few pockets of weak fine subangular blocky structure; sticky, plastic, firm; few very fine roots; many very fine and fine pores; continuous thick glaze coating on ped surfaces of strong brown color; many hard earthy lumps; many oxide fragments.
B2.6	Below 52	Dark reddish-brown (5YR 3/4) silty clay loam, with stringy mottles of strong brown; moderate very fine and fine subangular blocky structure; sticky, plastic, friable; no roots; many very fine and medium pores common; continuous thick glaze on ped surfaces and in pores; many very fine gibbsite particles that impart gritty feel to soil.

*Printed with permission of the Honolulu Office, U.S. Soil Conservation Service.

†Similar features in soil of temperate zones usually indicate clay skins; in this instance they are gelatinous masses of iron and aluminum oxide which dehydrate irreversibly upon air drying.

The data from the U.S.W.B. gage have been taken for total rainfall per month; this and approximate evaporation data are shown in table 2. The data from the recording rain gage were used for rainfall analysis (figures 2–6).

In presenting the latter data it has been necessary to group certain figures together to gain an intelligible picture, necessitated by the large number of rainfalls of low intensity.

The number of rainy days tends to be somewhat greater during the "summer" months (assumed as April to September) than the "winter" months (assumed as October to March), as shown in table 3. A somewhat arbitrary division between summer and winter in the Hawaiian Islands can be made due to the tradewind pattern. Tradewinds shift to the northern hemisphere in the "summer" and steadily blow from a north-easterly direction.

On the windward side of the Hawaiian Islands clouds bank up steadily against the central island mountain cores during this period. The small difference in evaporation between summer and winter and a large number of small rainfalls during the "summer" are explained from this weather pattern, the experimental area being situated on the windward side of Kauai.

The small annual variation in evaporation has called attention to the reliability of the method of measurement. It is known that a small error is introduced by rain in the recording method used. However, data taken at a comparable windward site at Hilo, Hawaii, show the same trend in evaporation behavior as on Kauai, as shown in table 4. It is thus assumed that the measurements made give a reasonably good approximation of pan evaporation at the experimental site. On this presumption, the data in table 2 indicate excess rainfall over evaporation during the winter, but at times small moisture deficiencies during the summer months.

The rainfall pattern during the period of measurement has probably been typical for the area. It included heavy rain during the following periods:

Aug. 6 and 9, 1959–7.66 inches
Nov. 2 and 3, 1959–5.07 inches
Feb. 19, 1960–2.62 inches
Mar. 6 and 7, 1960–2.90 inches
Oct. 2 and 3, 1960–5.30 inches

However, the period does not include unusually heavy storms. The frequency of such storms is illustrated in table 5 by an analysis made by the U.S. Weather Bureau (1959). This analysis applies to Lihue, 7 miles away from the experimental site.

At Kilauea, at the north side of the island of Kauai, the record rainstorm was 24.8 inches in 24 hours in January, 1956. These data do not give a complete picture as to the size of storms which can be expected. Rainfall, even though of less magnitude than quoted, but extending over several days, may be significant from an erosion point of view. However,

TABLE 2. Rainfall and approximate pan evaporation at the experimental area at Wailua Game Reserve, Kauai (altitude approximately 500 feet), from January 19, 1959, to October 6, 1960 (626 days)

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1959	*Jan. 19–31*					*inches of water*							
Rainfall	0.71	3.97	3.26	3.76	4.51	2.01	4.82	11.96	5.46	1.95	10.32	6.74	59.47
Evaporation		2.80	3.72	3.30	3.72	4.80	4.34	4.96	missing	4.03	3.60	3.30	
1960										*Oct. 1–6*			
Rainfall	5.21	6.59	11.95	3.85	4.10	3.98	3.93	4.51	5.37	5.84			55.33
Evaporation	3.30	3.77	4.03	3.60	3.72	4.50	3.72	4.34	3.90				

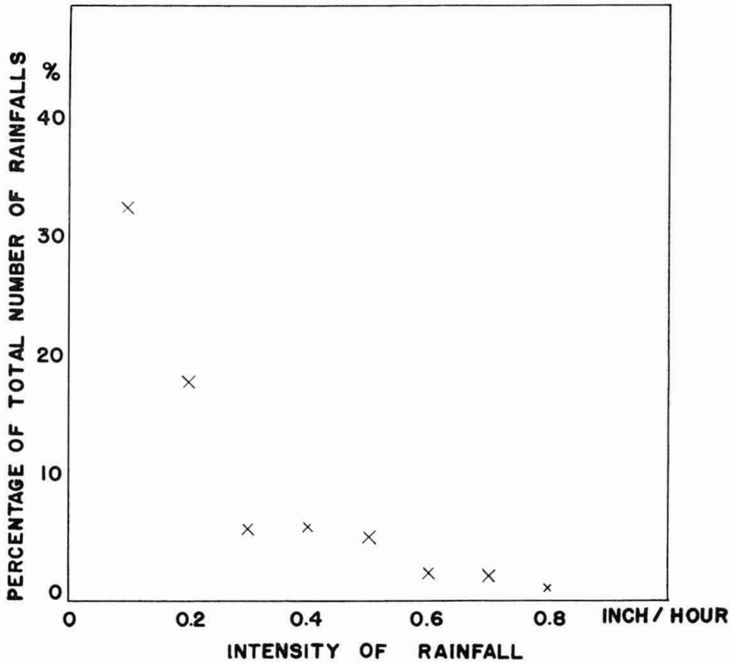


FIG. 2. Number of rainfalls of intensities between 0.1 and 0.8 inch per hour.

TABLE 3. Number of rainy days at experimental area

	WINTER* 1958/59	SUMMER† 1959	WINTER* 1959/60	SUMMER† 1960
October			15	
November			19	
December	16		20	
January	12		17	
February	18		18	
March	18		21	
April		14		23
May		21		26
June		19		22
July		21		24
August		28		28
September		21		27
	64	124	110	150

*Number of rainy days during winter: 17.4.
†Number of rainy days during summer: 22.4.

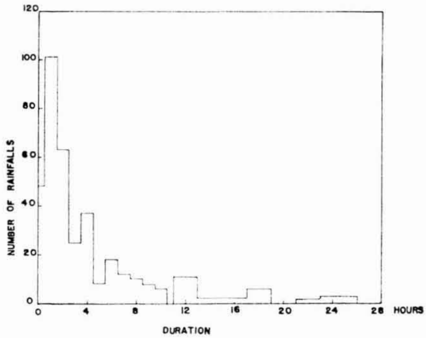


FIG. 3. Duration of rainfalls of intensities less than 0.1 inch per hour.

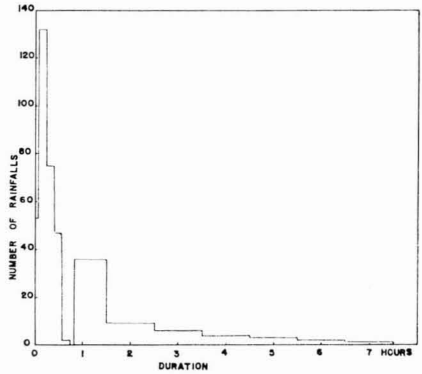


FIG. 4. Duration of rainfalls of intensities between 0.11 and 0.5 inch per hour.

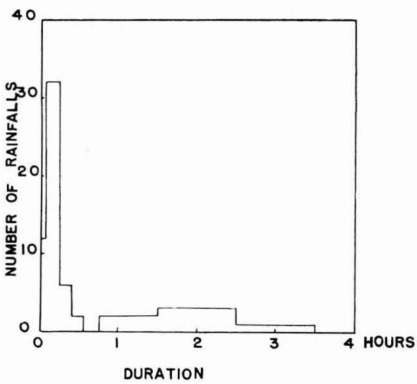


FIG. 5. Duration of rainfalls of intensities between 0.51 and 1.0 inch per hour.

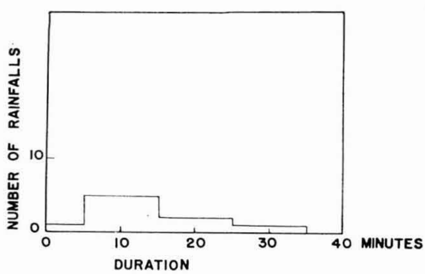


FIG. 6. Duration of rainfalls of intensities greater than 1.0 inch per hour.

TABLE 4. Pan evaporation at Hilo Airport, Hawaii (altitude 30 feet)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL TOTAL
						inches of water							
1956	5.38	4.14	5.17	5.49	4.94	5.78	6.68	5.56	6.43	4.65	3.33	4.91	63.06
1957	4.56	4.71	6.39	5.31	6.41	7.51	6.34	5.65	6.48	6.52	3.74	3.87	67.49
1958	7.04	5.17	6.15	5.69	5.70	6.86	6.00	5.86	5.05	5.29	3.86	5.87	68.54
1959	4.27	5.20	6.28	5.26	6.59	7.73	7.61	7.10	4.86	5.70	4.22	3.37	63.19

TABLE 5. Estimated return period of unusually heavy rain at Lihue, Kauai

TOTAL RAIN, INCHES/24 HOURS	MEAN RETURN PERIOD, YEARS
5.6	2
8.9	5
11.1	10
16.0	50
18.0	100

such storms are probably as infrequent as the ones cited, and for the purpose of planning against erosion, it is believed that a consideration of the above probabilities may suffice.

EXPERIMENTAL PROCEDURE

Experimental approach

Erosion assessment has been made in two ways:

(1) Systematic plot experiments have been conducted on the effect of various surface treatments on soil erosion on subsoil exposed after stripping, on a section of the 2½ acres of stripped land.

(2) Field observations have been made on the extent of displacement of the many tons of soil (estimated at over 100,000 tons) dumped on the valley slopes. In addition to making photographic records of the behavior of the talus slopes, the extent of silting up of the water courses in the valley floors has been followed.

Experimental plots

Twelve plots, measuring 8 × 80 feet, were laid out side by side. Six surface treatments in duplicate have been tested in these plots, as is discussed below. Two more plots were laid out approximately 400 feet away from the stripmined site on surface soil under undisturbed native vegetation on an 8 percent slope. These two plots served as controls.

The 12 adjacent plots were laid out on a slope averaging 5 percent in the lengthwise and 0 to 2 percent in the crosswise direction of the plots. An attempt was made to eliminate cross-slope within each plot by hand levelling, but owing to settling this has not been completely successful. Because of cross-slope, some adjacent plots had to be stepped; that is, they were at different levels.

To simulate an effect of mining operations in creating surface soil compaction, a loaded dump truck was run for several hours forward and backward over the plot site. Bulk density samples were taken from the thus compacted and "uncompacted" soil.

The long sides and the top end of the plots were delineated by 8-inch-wide, 14-gage galvanized metal strips. These were set on edge at the plot boundary, pounded 4 inches into the soil, and secured in position by angle iron stakes. Where the difference in level between adjacent plots made this necessary, two strips were inserted, one above the other. Angle brackets were inserted in the corners to exclude water inflow from beyond the plots. In addition, the 12 adjacent plots were surrounded by shallow surface drains.

Plot treatments

The following treatments have been applied:

Unprotected subsoil

(1) Subsoil kept devoid of plant cover.
(2) Subsoil scarified and covered by approximately 6 inches of topsoil, similarly kept devoid of plant cover.
(3) Subsoil kept devoid of plant cover, contour treated.

Surface-protected subsoil

(4) Subsoil covered by approximately 2 inches bagasse (sugar cane trash), a local waste product of little commercial value.
(5) Subsoil worked up into a seedbed by shallow tillage, fertilized, and planted with cuttings of Pangola grass (*Digitaria decumbens*).
(6) Subsoil scarified and covered by approximately 6 inches of topsoil, worked into a seedbed, fertilized, and planted with Pangola, as in treatment 5.
(7) Control—Surface soil covered by native vegetation in a separate area.

An attempt being made to randomize treatments, the arrangement of the 12 adjacent plots (treatments 1 to 6) worked out as follows, adjacent plots being numbered consecutively:

Plot No.:	1	2	3	4	5	6	7	8	9	10	11	12
Treatment No.:	3	5	4	1	6	2	2	6	5	1	4	3

The plots with treatments 1, 2, and 3 were kept devoid of plant cover by applying Urox at the rate of 200 pounds per acre. However, occasional hand weeding was necessary at a later date.

It was desirable to lay out treatment 2 next to treatment 6, thus giving 4 adjacent plots on which surface soil was replaced, to allow machinery to be used in preparing the plots. Before applying surface soil, the level of the subsoil was further lowered by approximately 6 inches and scarified by a rotary hoe. The surface soil was then placed upon it from a dump truck and spread by hand till the level of the land was approximately the same as that of adjacent plots.

Contour treatment consisted initially of three soil checks, 6 inches high, placed across the plots at 20 feet interdistance. It became soon apparent that no proper assessment of contour treatment could be made in this manner, as surface runoff accumulating up-slope of the checks could not escape laterally on, or close to, the contour. The treatment was thus modified in September, 1959. Three shallow drains, each backed on the down-slope side by a 6-inch-high soil check, were installed in the same positions as before. Runoff accumulating in these drains was led through a gap in the metal border strip to a surface drain beyond the plots. This treatment was kept under ocular observation only for 1 year.

The bagasse application (treatment 4) was repeated in August, 1959, to make up for decomposition of the material.

The plots in treatments 5 and 6 were fertilized in August, 1958, on the basis of 1250 pounds per acre mixed fertilizer (formula 18-21, 2-12, 5) and 5000 pounds per acre lime. The general fertilizer application was repeated in August, 1959.

Pangola grass was planted in August, 1958. By October of that year a satisfactory cover had been established. At that time, measurements were started, but it was then found that some flumes had tilted because of "underflow" under the sill. The flumes, having previously been set in soil, were lifted and re-set in concrete. The plots were ready for measurement on January 19, 1959.

The Pangola plots were mowed by a sickle-bar mower when the grass reached a height from 8 to 12 inches; the sward was then reduced in height to 3 or 4 inches.

Infiltration measurements and aggregate analyses

Infiltration data were collected in August, 1958, using the method described by Haise, *et al.* (1956). The measurements were made in 8- to 10-fold on the following sites:

(1) On surface soil under native vegetation.

(2) On soil under native vegetation, 14 to 18 inches below the original surface.

(3) On stripmined soil, 10 to 15 feet below the original surface.

(4) As (3), but after plowing. The soil in the infiltrometers was smoothed by hand prior to applying water.

A second set of data was collected, this time on the erosion plots, in April, 1960, taking measurements in 4- to 6-fold by the same method. Some aggregate analyses were made in April, 1960, in an attempt to find an explanation for differences in erosion behavior observed, using the method described by Yoder (1936).

Method of measuring erosion on the plots

Conventionally, soil and water losses are measured separately for each treatment. Several techniques have been developed for this purpose which, however, are elaborate and expensive. The reporters know of only one reasonably inexpensive device for measuring soil and water for each plot: the Coshocton runoff sampler (Parson, 1954). On studying the possible use of this device it was learned that difficulties were encountered under field conditions because of clogging and a variation in speed of rotation of a disc used for soil and water-interception, except when used on grass plots.

Under the given circumstances, measurement of soil losses only for each treatment was considered adequate. Water losses were measured in one measurement for all 12 adjacent plots. The presumption was made that water losses from each plot could be assessed by proportioning the total water flow for the 12 plots over the individual plots according to soil losses measured for each plot. Any failure in being able to do so satisfactorily was not considered important, because (1) soil losses were considered more important than water losses, and (2) water losses could be assessed from ocular observations on damage done on the plots, on the surrounding stripmined area, and in the valley floors carrying away surface runoff.

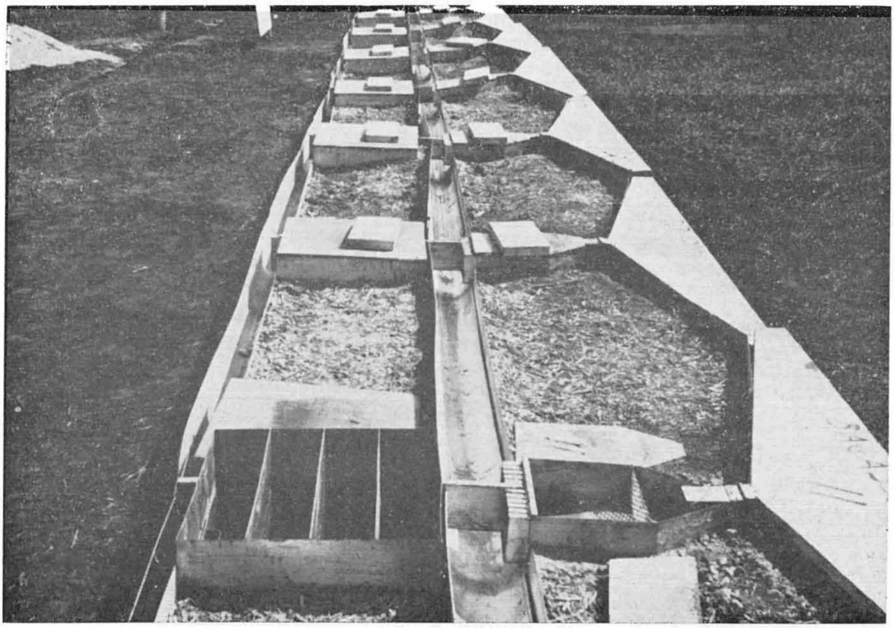
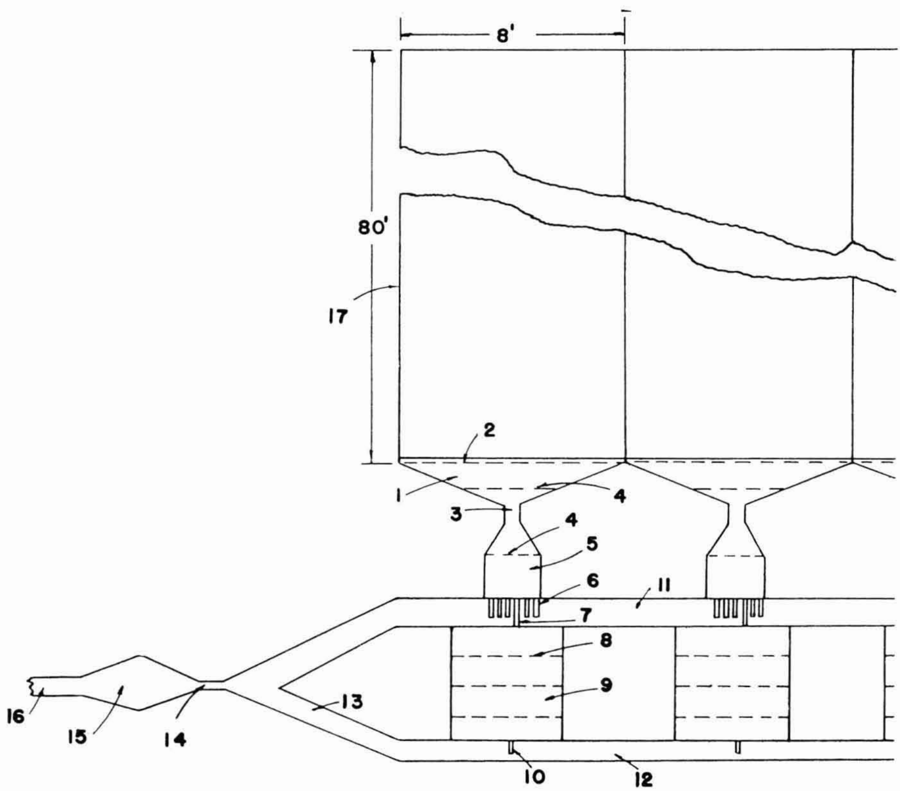


FIG. 7. The measuring technique at the bottom end of the 12 adjacent plots.



LEGEND

1. Sill
2. Coarse screen in sill for intercepting trash
3. Inlet throat
4. Coarse screen for intercepting trash
5. Divider box
6. Flow dividers
7. Inlet throat to silt trap for 1/12th flow
8. Baffles with offset holes
9. Silt trap
10. Overflow outlet of silt trap
11. Aluminum flume intercepting 11/12th flow
12. Aluminum flume collecting overflow from silt trap
13. Divergent flume
14. 6-inch throat of Parshall flume
15. Convergent flume
16. Drainage flume
17. 8-inch-wide metal strip set on edge to delineate plots

FIG. 8. Details of the erosion-measuring technique—diagrammatic.

The mechanism developed is shown in figures 7 and 8. Water and soil collecting at the bottom ends of the plots are intercepted by a sill and channeled via a throat into a divider box. On the downstream side of this box 12 slots divide the flow. Soil and water passing through 11 slots run to waste via an 8-inch aluminum flume. One slot passes soil and water into a silt trap or sedimentation tank from where the water goes to waste via a 4-inch aluminum flume, after the tank has filled to 6 inches above

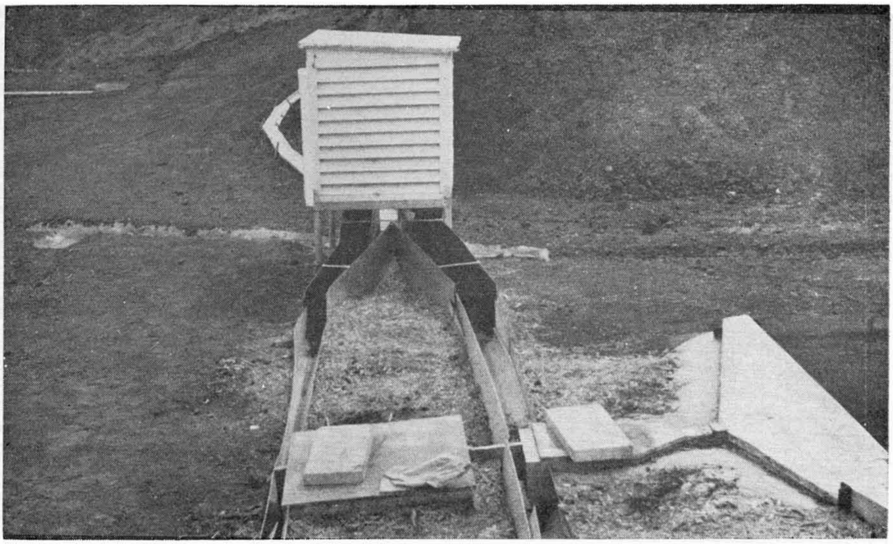


Fig. 9. Runoff water was measured in one measurement from all 12 adjacent plots by a recording Parshall flume (inside housing).

the bottom. Silt settling in this tank is induced by three baffles with offset holes through which incoming water has to pass. All the equipment, with the exception of the conducting flumes, was manufactured of 18-gage galvanized metal, painted with aluminum paint.

Water running to waste via the 4- and 8-inch flumes was measured by a recording Parshall flume with a 6-inch throat (figure 9). Beyond the Parshall flume the waste water was conducted through 6-inch boiler pipe underneath the boundary road and run via additional flume to a vegetated slope.

The device measuring soil losses was set in concrete, as mentioned, to insure a permanently horizontal position of the divider box in the direction of the width of the plots. To prevent underflow below the sill, a 6-inch metal sheet set on edge was pounded in at the soil-metal interface until the upper edge was flush with the surface of the sill and thus of the soil. Any space between this sheet and the sill edge was sealed with asphaltic putty.

To measure soil movement on the plots, metal stakes were driven into the soil. Across the plot width, one stake was placed in the center and one on each side between the center and the plot edge. Along the plot length, sets of stakes were inserted at 20 feet interdistance. The length of the stakes above the soil surface on the downslope side, measured at intervals by a tape, was supposed to indicate any downslope soil movement.

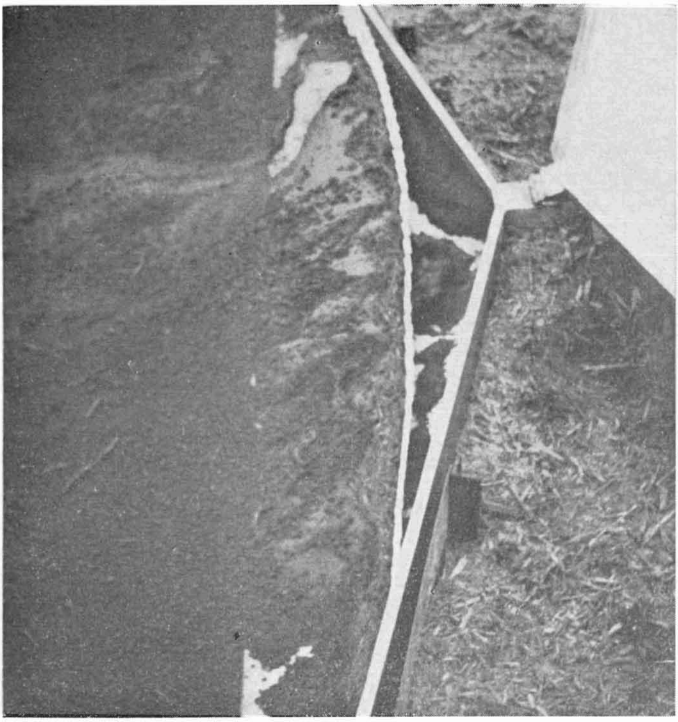


FIG. 10. In order to keep the measuring device operating satisfactorily, it is necessary to periodically clean the sill and divider box. The soil removed is taken into account in soil loss computations.

Sample taking

The interval between measurements of soil losses by the device at the bottom end of the plots was dictated by the quantity of soil that had accumulated within the sill and the divider box (figure 10) and in front of the sill on the plot above the original soil surface (figure 11). This quantity was added to the soil losses measured by the sedimentation tank. Such a procedure does not seem to have been described before and the following justifications are given for this action.

(1) The divider box stops proportioning 1/12th and 11/12th flow by any soil deposition within the slots. Regular inspection of the slots was thus a routine job of the foreman supervising the experimental area.

(2) Keeping the slots clean necessitated periodic removal of the soil within the divider box and sill.

(3) Collecting soil accumulated in front of the sill is warranted because,

(a) lack of removal led to channeling through the accumulated soil (figure 11),

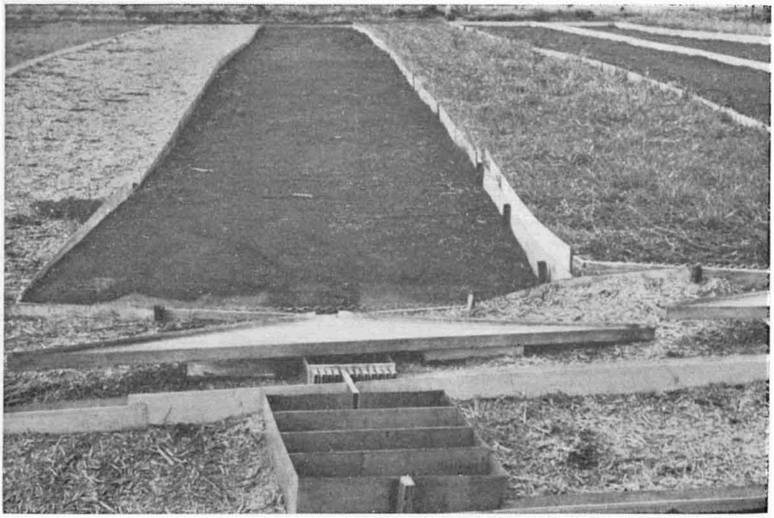


FIG. 11. Soil accumulation in front of the measuring device at the bottom of the plots is induced by the soil-metal boundary. To prevent channeling (see photo) the thus accumulated soil must be removed and be taken into account in soil loss computations.

(b) in some places runoff tended to overtop the plot boundary,
(c) the metal-soil boundary, although inconspicuous to the eye, formed a distinct barrier to soil movement from the plot into the measuring device (figure 11).

The extent to which accumulated soil referred to in (3) is removed is subject to judgment. It has been found satisfactory to remove the soil that had accumulated above the level of the sill and thus above that of the original soil surface, up to 2 feet upslope from the sill edge.

The soil fraction from the sedimentation tank was collected by siphoning off the clear water on top by a garden hose and collecting the bottom sediment by a sponge. This sponge was squeezed into a canvas bag. The bag was then closed by a string at the top and allowed to drain by suspending it from a fence. Soil lost on drainage was insignificant. The quantity of soil collected in this manner, after drying, has been multiplied by 12.

RESULTS

Erosion losses from the plots

Unprotected subsoil

The results of the measurement of soil losses on the plots are shown in tables 6 and 7. Table 6 shows the total soil losses measured. In table 7 losses are shown according to whether the soil was collected from the silt trap or sedimentation tank (indicated by "trap"), or within other parts and

TABLE 6. Total soil losses measured in erosion plots in duplicate from January 19, 1959, to October 6, 1960

TREATMENT	1959 JAN. 19–FEB. 20	1959 APR. 22	1959 JUNE 15	1959 AUG. 17	1959 NOV. 18	1960 FEB. 11	1960 APR. 12	1960 JULY 29	1960 OCT. 6	TOTAL PER PLOT	AVERAGE TOTAL SOIL LOSSES: Depth in inches	AVERAGE TOTAL SOIL LOSSES: Pounds per acre	AVERAGE TOTAL SOIL LOSSES: Short ton per acre
	0.01 inch depth of soil												
UNPROTECTED SOIL													
Bare subsoil	4.4	6.0	2.0	12.7	56.0	2.3	37.9	1.3	30.3	152.9			
	2.2	4.2	0.8	7.9	34.6	0.7	31.2	1.6	2.2	85.4	0.1192	31,000	15.5
Subsoil + replaced	0.4	1.4	0.1	4.9	3.0	0.5	1.2	0.3	0	11.8			
topsoil	4.1	5.7	0.1	7.1	4.2	0.8	12.9	0.3	1.9	37.1	0.0245	6,400	3.2
Subsoil, contour	7.0	8.8	2.0	25.7							0.0435	11,300	5.7
treated	6.2	7.9	5.7	16.5							0.0363	9,500	4.8
PROTECTED SOIL													
Subsoil + bagasse	0.3	0.7	0.3	3.0	0.3	0.1	0.1	0.4	0.2	5.4			
	0.3	0.8	0.4	1.2	0	0	0	0.5	4.1	7.3	0.0064	1,900	1.0
Subsoil + Pangola	0.6	1.1	0.4	3.4	0.3	0	0.3	0.1	0.2	6.4			
	0.3	0.7	0.2	2.5	0	0	0	0	0	3.7	0.0050	1,300	0.7
Subsoil + replaced	0.3	0.7	0.3	1.6	0	0	0	0	0	2.9			
topsoil + Pangola	0.4	0.8	0	4.1	0	0	0	0	0	5.3	0.0041	1,100	0.6
Undisturbed native vegetation	0	0.1	0	0	0	0	0	0	0	0.1			
(control)	0.2	0	0	0	0	0	0	0	0	0.2	0.0002	50	–

TABLE 7. Soil losses collected from (1) silt trap (sedimentation tank) and (2) sill, divider box and from bottom end of plot in front of sill, expressed in terms of a layer of soil 1/1000th of an inch thick

TREATMENT	1959 JAN. 19–FEB. 20		1959 APRIL 22		1959 JUNE 15		1959 AUG. 17		1959 NOV. 18		1960 FEB. 11		1960 APRIL 12		1960 JULY 29		1960 OCT. 6		TOTAL	
	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill	Trap	Sill
UNPROTECTED SOIL																				
Bare subsoil	1.4	3.0	2.8	3.2	0.4	1.6	6.3	6.4	1.0	55.0	0.4	1.9	1.1	36.8	0.6	0.7	1.3	29.0	15.3	137.6
	0.7	1.5	2.7	1.5	0.4	0.4	3.2	4.7	1.8	32.8	0.2	0.5	0.9	30.3	0.4	1.2	0.6	1.6	10.9	74.5
																		Av.	13.1	106.1
Subsoil + replaced topsoil	0.2	0.2	0.6	0.8	0	0.1	3.4	1.5	0.4	2.6	0.1	0.4	0.2	1.0	0	0.3	0	0	4.9	6.9
	2.6	1.5	4.1	1.6	0	0.1	4.6	2.5	0.9	3.3	0.2	0.6	7.5	5.4	0	0.3	1.9	0	21.8	15.3
																		Av.	13.4	11.1
Subsoil, contour treated	1.8	5.2	3.2	5.6	0.4	1.6	11.0	14.7											16.4	27.1
	1.9	4.3	3.4	4.5	0.7	5.0	8.6	7.9			No Record								14.6	21.7
																		Av.	15.5	24.4
PROTECTED SOIL																				
Subsoil + bagasse	0.2	0.1	0.6	0.1	0.2	0.1	1.9	1.1	0.1	0.2	0	0.1	0.1	0	0.1	0.3	0.2	0	3.4	2.0
	0.1	0.2	0.6	0.2	0.2	0.2	0.5	0.7	0	0	0	0	0	0	0	0.5	0.3	3.8	1.7	5.6
																		Av.	2.6	3.8
Subsoil + Pangola	0.3	0.3	0.8	0.3	0.2	0.2	3.1	0.3	0.1	0.2	0	0	0	0.3	0.1	0	0.2	0	4.8	1.6
	0.3	0	0.6	0.1	0.2	0	2.4	0.1	0	0	0	0	0	0	0	0	0	0	3.5	0.2
																		Av.	4.1	0.9
Subsoil + replaced topsoil + Pangola	0.2	0.1	0.6	0.1	0	0.3	1.5	0.1	0	0	0	0	0	0	0	0	0	0	2.3	0.6
	0.4	0	0.8	9	0	0	4.0	0.1	0	0	0	0	0	0	0	0	0	0	5.2	0.1
																		Av.	3.8	0.3
Undisturbed native vegetation (control)	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0

outside of the measuring device (indicated by "sill"). Soil losses were moderately heavy on bare subsoil and on contour-treated soil, but were much less on subsoil with replaced surface soil. Table 7 shows that the bulk of the soil losses in treatments 1 and 3 were derived from the "sill" fraction. Particularly after heavy rain, as occurred in the beginning of August and November, 1959, the end of February and the beginning of March, 1960, and in the beginning of October, 1960, much soil accumulated in front of the sill. This accounts for the high readings under "sill" on August 17 and November 18, 1959, and October 6, 1960.

Surface-protected subsoil

Tables 6 and 7 show no soil losses on the plots under native vegetation. On the bagasse- and grass-covered plots soil losses were small. It is of interest to note that the "sill" fraction was much smaller than on the plots with unprotected soil.

The fact that no soil losses were measured on certain dates does not mean that no soil and water movement did take place. Table 8 shows the depth of water in the sedimentation tanks at the time of measurement. Comparing these data with those in tables 6 and 7, it is clear that water runoff did occur even when no soil losses were measured. This is particularly marked on the plots in native vegetation.

This raises the question: how reliable are the measurements of soil losses? It is apparent from the well-dissected topography of the Wailua Game Reserve that significant geologic erosion has taken place. Yet, the plot measurements almost deny any soil movement under native vegetation.

An answer to this problem has been provided by the observations made on the bagasse-covered plots, as follows.

As, owing to decomposition, bagasse gradually disappeared, the remaining bagasse accumulated in crescent-shaped bands (figure 12). Soil moved from the bare spots between the bands and accumulated on the concave, up-slope side of the bands to such an extent that up to a 1-inch difference in level between the concave and convex sides was created. Therefore, soil moving down the slope was intercepted by surface roughness.

A close scrutiny on the other surface-protected plots revealed similar interception of soil by surface roughness. During rain it could be observed that various elements of surface roughness, litter, trailing roots, but particularly bagasse, were effective in creating surface storage, not only for soil, but also for water. Native vegetation and the dense grass cover on the plots with added surface soil (table 9) were most effective in this respect (table 8). The lighter cover on plots with subsoil only was less effective (table 8). A comparison of tables 6 and 9 shows that a 100 percent cover is not required for effective surface detention.* Bagasse remained effective when the percentage cover was 15 percent only.

*"Detention"—water detained and stored at the soil surface during rain.

TABLE 8. Average depth of water in inches in sedimentation tanks of surface-protected plots, at time of measurement

TREATMENT	1959 FEB. 20	APR. 22	JUNE 15	AUG. 17	NOV. 18	1960 FEB. 11	APR. 12	JULY 29	OCT. 6
Subsoil + bagasse	3	6	5½	6	6	6	6	4	6
Subsoil + Pangola	2½	6	3	6	6	6	0	1½	5
Subsoil + topsoil with Pangola	0	½	0	6	4½	5	0	0	1
Native vegetation	5	0	0	6	6	5	4½	0	3½

TABLE 9. Estimated percentage of bare soil surface visible on surface-protected plots

TREATMENT	1959 FEB. 20	APR. 22	JUNE 15	AUG. 17	NOV. 18	1960 FEB. 11	APR. 12	JULY 29	OCT. 6
Subsoil + bagasse	15	20	25	15	35	50	60	70	85
Subsoil + Pangola	50	40	20	20	20	20	15	10	10
Subsoil + topsoil with Pangola	10	10	5	5	5	5	5	5	5
Native vegetation	10	10	10	10	10	10	10	10	10

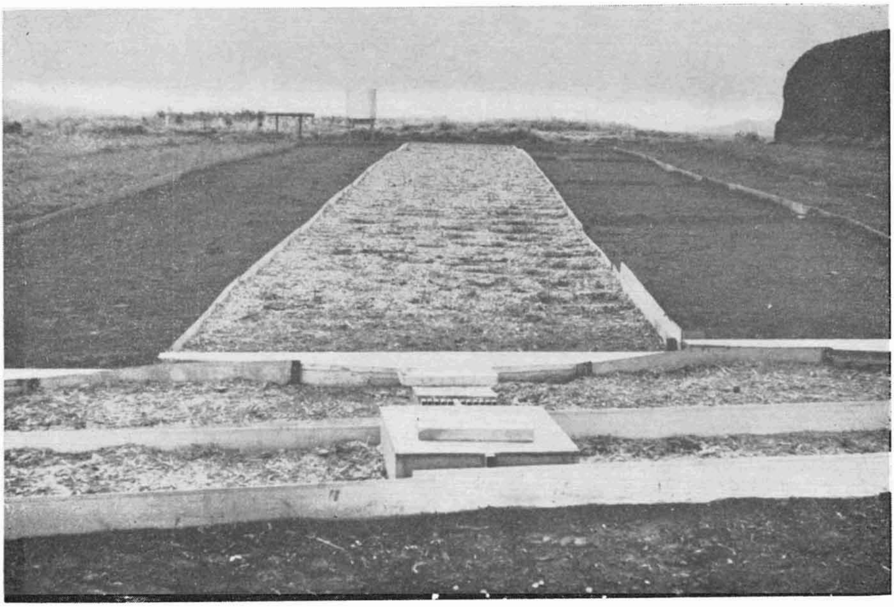


FIG. 12. After decomposition, remaining bagasse accumulates in crescent-shaped bands (central plot) which hold dislodged soil back. A beneficial effect of bagasse is entirely due to its surface storage capacity. (Note depth of stripping in right background.)

The metal stakes inserted for supplying quantitative data on soil displacement on the plots turned out to be useless. The differences between initial and ultimate surface level were so small or so irregularly distributed that no significant trend could be demonstrated on analyses. Only the soil accumulation at the bottom end of the plots with unprotected soil (figure 11) showed up.

Contour treatment

The three checks initially provided across the plots for erosion control caused runoff water to accumulate on their up-slope side. However, heavy rain led to overtopping of the checks and a break-through at the lowest point. This, in turn, led to channeling and gullying on the down-slope side. The heavy soil loss recorded (table 6) is due to this process.

The treatment as modified in September, 1959, provided an opportunity for the lateral escape of runoff to a surface drain beyond the plot boundary. It was soon learned that the drains should be laid on such a grade that the velocity of water within them was high enough for granular material to be washed out. This granular material was derived from "self-mulching" of the subsoil (page 29). It soon tended to choke surface drains laid on a flat grade, after which, overtopping occurred as in the last treatment. A grade of 4 percent appeared reasonably satisfactory, but under all circumstances periodic cleaning of the drains remained a necessity.

Water losses from the plots

The large Parshall flume (6-inch throat) selected enabled the recording of the effect of heavy rain. This flume, however, did not record small flows. Therefore, only on 3 days a measurable flow was recorded (table 10). On 2 days the float got obviously stuck, as it did not restore its position at the end of the flow and no record of duration is available (February 18 and September 29). Only the measurement on August 6 could, if desired, be proportioned over the various plots according to soil losses measured. Under the circumstances this type of analysis does not seem important.

TABLE 10. Total water flow from the 12 adjacent erosion plots, measured by a recording Parshall flume

DATE	RAINFALL INTENSITY, INCHES	FLOW, C.F.S.	DURATION OF FLOW
1959			
April 5	0.75 in 10 minutes	trace	
	0.40 in 1 hour		
August 6	1 in 3½ hours	average 0.15	2 hours
	0.5 in 2 hours		
	0.3 in 2 hours		
1960			
February 18	2 in 2 hours	maximum 0.18	not recorded
March 2	1.4 in 2 hours	trace	
September 29	1.7 in 2 hours	maximum 0.11	not recorded
October 1	0.64 in 15 minutes	trace	
October 2	1.24 in 4 hours	trace	
	1.15 in 2 hours		
	0.70 in 30 minutes		

Soil compaction

Soil compaction induced by stripping and by running a loaded dump truck for several hours over the site of the 12 adjacent plots had caused the surface 2 inches of soil to become compacted approximately 10 percent.

The average bulk density measured in the thus compacted soil was 1.27 in the 0–2-inch layer, 1.17 in the 3–4-inch layer, and 1.14 in the 5–6-inch layer. Below this layer the latter value was maintained.

Infiltration measurements

The results of the measurements made in August, 1959, are shown in table 11. Very high infiltration rates were recorded on surface soil under native vegetation. The soil at 12 and 14 inches depth yielded values less than one-tenth of those for the surface soil. At greater depth below the original surface, infiltration was much higher than on shallow subsoil but less than half of that of the surface soil. The plowed subsoil showed substantially higher infiltration rates than the unplowed subsoil.

TABLE 11. Average rate of infiltration in inches per hour on surface soil and subsoil in August, 1958*

LAPSED TIME, MINUTES	SURFACE SOIL SITE 1	SUBSOIL 14″–18″ DEPTH SITE 2	SUBSOIL 10′–15′ DEPTH SITE 3	SUBSOIL 10′–15′ DEPTH SITE 4 (PLOWED)
		inches per hour		
15			6.0	10.0
30	26.0	1.6	4.0	8.8
45			3.0	7.8
60	21.0	1.2	2.6	7.0
90	17.5	1.0	2.1	6.0
120	16.0	0.9	1.8	5.2
150	15.0	0.8	1.6	4.8
180	14.5	0.8	1.5	4.4
210	14.0	0.8	1.4	4.2
240	13.5	0.8	1.3	4.0

*Data collected by W. E. Holmes, former Assistant Soil Scientist, Hawaii Agricultural Experiment Station.

The measurements made in April, 1960, are recorded in table 12. The plots with replaced topsoil showed very high infiltration rates, approximately as high as the surface soil under native vegetation. Under Pangola the rate was the same as those for shallow subsoil (table 11). The bagasse plots yielded relatively low infiltration rates.

TABLE 12. Average rate of infiltration in inches per hour on the erosion plots in April, 1960

SUBSOIL PLUS TOPSOIL, DEVOID OF VEGETATION		SUBSOIL, FERTILIZED AND PLANTED WITH PANGOLA		SUBSOIL PLUS BAGASSE	
Lapsed time, minutes	Inches per hour	Lapsed time, minutes	Inches per hour	Lapsed time, minutes	Inches per hour
5	37.2	5	4.2	5	1.0
10	18.0	15	3.3	15	.3
15	19.8	30	2.6	35	.15
20	15.0	60	2.1	95	.20
35	16.2	90	1.9	155	.10
45	14.4	120	1.8	215	.13
55	19.0	180	1.8	275	.15
60	21.5	240	1.7	335	.12
70	13.3	360	1.6		

Aggregate analyses

The results of aggregate analyses are shown in table 13. Comparing subsoil only, with surface soil replaced on the subsoil, the large fraction of stable aggregates of large size in the replaced soil is shown up. The data also show that after almost 2 years, no improvement in soil aggregation under Pangola grass was apparent.

Different values were obtained from aggregate analysis depending on whether or not the samples had been air-dried before measurement.

Air-drying of soil samples before aggregate analysis reduced the amount of the larger aggregates, even when a sample had been slowly re-wetted by capillary action. Irreversible dehydration of oxides occurring as slimy coatings on ped surfaces (see profile description) into tiny aggregates (and thus ending their role as bonding agents within and around peds) may explain this observation.

Aggregate analyses, using moist and air-dried soil, did not throw any light on the curious behavior of self-mulching.

Self-mulching

Self-mulching of subsoil has been observed on the erosion plots, elsewhere on the experimental area, and in some other localities in the Hawaiian Islands.

On the experimental plots there was a tendency for unprotected subsoil to form and maintain a loose, granular surface mulch. This mulch is usually 2 to 3 granules in thickness, but pockets form along the floor

TABLE 13. Aggregate analysis of soil on the erosion plots (soil from 0–6 inches depth)

TREATMENT	AGGREGATE SIZE, MM	MOIST SOIL, %	AIR-DRIED SOIL, %
Subsoil, devoid of vegetation	2.0	36.4	13.5
	0.84–2.0	19.8	7.3
	0.42–0.84	18.0	16.3
	0.24–0.42	7.9	15.3
	0.10–0.24	8.3	21.7
	0.10	9.6	25.9
		100.0	100.0
% moisture (by oven-dried weight of soil)		33.1	20.1
Subsoil with replaced topsoil, devoid of vegetation	2.0	53.2	42.5
	0.84–2.0	20.0	22.1
	0.42–0.84	13.6	16.5
	0.24–0.42	5.0	6.7
	0.10–0.24	4.7	6.3
	0.10	3.5	5.8
		100.0	99.9
% moisture		42.9	24.2
Subsoil, fertilized and planted with Pangola	2.0	33.7	19.9
	0.84–2.0	17.9	13.7
	0.42–0.84	18.0	23.5
	0.24–0.42	8.7	14.4
	0.10–0.24	9.2	16.7
	0.10	12.6	12.4
		100.1	100.6
% moisture		35.6	25.2

of drainage channels. The manner in which this mulch originates is not yet understood. After stripping the surface soil, a subsoil of a sticky, plastic consistency and with a smooth surface is exposed. Perhaps following alternate wetting and drying, soil material at the surface consolidates into aggregates with a wide range of sizes.

Water flowing over the surface carries away the finer particles and all the mulch is removed by heavy rain, leaving a smooth surface. Several cycles of aggregate formation and removal of the aggregates leave a continuous mulch at the surface, except for 1 or 2 weeks after heavy runoff.

The talus slopes and valley bottoms

An attempt had been made to immediately stabilize the talus slopes by fertilization and broadcast-seeding of oats and other grasses. However, it took almost 1½ years before an adequate vegetative cover had been established. At that time the main cover consisted of molasses grass (*Melinis minutiflora*), aided by some re-established native plants.

Access roads surrounding the experimental area had been established on top of the dumped soil. It had been expected that this might add to slumping, but little slumping ever occurred.

Serious erosion took place only where drainage was not controlled. At sites where drainage water discharged onto the talus slopes in channels, gullying on the slope occurred. The significance of this gullying, of some minor slumping, and of sheet erosion, was followed up by regular inspection of the valley floors.

The soil deposited in the valley bottoms created a few local swampy spots which caused some native plants to be killed. However, streams have cut across these places and after a dry spell they are drained. The observations made have led to the conclusion that the damage done to the watershed has been of negligible significance.

Dumping the stripped soil on the steep valley slopes has been an unusually severe test of the erodibility of this soil. Normally, the stripped soil would be removed from the mined area for processing. The fact that so little erosion did take place gives evidence for the very low erodibility of this soil.

DISCUSSION

Applicability of results

The results obtained apply to conditions under which the experiments have been carried out. Consideration should thus be given to the soil, the topography, and the climatic regime during the period of measurement.

The soil on which the experiment has been carried out belongs to the Kapaa series and the results should be applicable to this soil, occurring in a belt from 200 to 1000 feet elevation on the east side of Kauai.

The slope on the experimental plots was approximately 5 percent, a grade to which any stripmined land in the area can conveniently be graded. The stripmined land should be graded to an even slope, as any abrupt change in slope leads to channeling of runoff water and consequent gullying.

The climatic regime during the period of measurement (tables 2 and 3; figures 2 to 6) is considered typical for the area. The period included a number of heavy rain storms, but did not include unusually heavy rain of more than 10 inches per day, which statistically occurs once in 10 years or at longer intervals (table 5).

Applicability is also subject to adequate provision for surface drainage. Surface runoff, being unavoidable, should be provided for by wide and shallow semicircular drains, presumably on a grade of approximately 4 percent. Runoff should be guided across roadways through culverts. If not too widely spaced, 6-inch boiler pipes can conveniently be used for this purpose. Discharge should be on a naturally-vegetated valley slope only.

Unprotected subsoil

The results of the measurements made in treatment 1 give a conservative estimate of erosion that can be expected on unprotected, compacted stripmined soil under average rainfall conditions. The conservatism arises from the existence of a cross-slope on the plots. This cross-slope caused runoff water to concentrate on the down-slope side across the plots, leading to channeling and some gullying along that side. Erosion losses were thus probably in excess of what would have occurred if runoff water had been able to follow the natural slope of the land. Pursuing the measurements over a longer period than has been done would probably have accentuated the unnatural effect of the cross-slope in the plots.

On the other hand, erosion losses would undoubtedly have been less if the induced compaction on the surface 2 inches had been offset by scarifying, as is indicated by the results from treatments 2, 5, and 6, and by tables 11 and 12.

The self-mulching property of the Kapaa subsoil undoubtedly provides some protection against erosion (as does any surface mulch), but obviously not an adequate protection.

Surface soil replacement

Surface soil replacement on subsoil drastically reduced erosion. This can be explained, firstly, from the scarification applied to the subsoil before surface soil replacement and, secondly, from the high structural stability of the surface soil (table 13).

However interesting these results are, it is unlikely that surface soil replacement should be practiced merely to combat erosion. Surface soil replacement should only then be contemplated when superior crop growth is to be achieved, as is discussed below.

Contour treatment

The observations made indicate that it is likely that some beneficial effect from contour drainage can be obtained. Drains may have to be spaced at close, say 50 feet, intervals.

However, the drain grade has been found to be critical due to choking of the drains by granular material derived from "self-mulching." Under the conditions of the experiment the grade should be approximately 4 percent. Under any condition the drains need to be cleaned periodically and during heavy rain it is possible that serious scouring in the drains will occur.

In view of these considerations contour treatment as a means of controlling erosion on stripmined land is not recommended.

Protected soil

Bagasse application

Bagasse application has virtually been as effective in erosion control as a grass cover, even when most of the bagasse had decomposed (tables 6 and 9).

The data in tables 11 and 12 support a conclusion that the infiltration rate under bagasse had not improved after 2 years cover. This is supported by field observations made in October, 1960. At that time the subsoil underneath bagasse had still the same smooth, compacted appearance and the same brick-red color as the soil which had remained unprotected. It is clear now that the subsoil should have been scarified prior to bagasse application.

It is considered possible to establish erosion control by the application of bagasse in patches. Such an application might allow simultaneous establishment of plant cover which could take over the function of erosion control from bagasse by the time this has decomposed.

Bagasse application should be limited to situations where a quickly-acting measure is required to combat an erosion hazard. However, bagasse cannot be counted upon at all times of the year. Moreover, bagasse is bulky and, therefore, expensive to transport. For general erosion control, bagasse should not be relied upon.

Revegetated subsoil

Pangola grass has proved to be efficient for erosion control. However, it took approximately 3 months for the plants to adequately establish themselves. Therefore, a combination of Pangola with a quick, evanescent cover should be aimed at. For this purpose, bagasse or a crop like oats might be used.

It is considered likely that also during unusually heavy rain (more than experienced—table 5), Pangola would be reasonably efficient in erosion control.

Erosion control on grass-covered subsoil is due to the surface detention which the cover creates (tables 6 and 8). To this, dissipation of energy in the falling raindrops should be added. It is also due to an increase in infiltration rate (table 12). It is of interest to note that a high infiltration rate was not paralleled by high structural stability of the soil under Pangola (table 13).

Re-establishment of plant cover should thus be the major means of erosion control. This, however, requires substantial fertilizer application (Younge and Moomaw, 1960). In the absence of fertilizer application, the subsoil is hardly capable of supporting any vegetative cover. This is evidenced by bare sites found in the neighborhood of the experimental area, stripped many years ago.

The effectiveness of a plant cover in controlling erosion has been demonstrated for Pangola grass. It seems reasonable to assume that a whole range of crop plants will be as effective as Pangola, provided they create adequate surface detention. Therefore, widely spaced shrubs or trees with bare soil in between are not recommended for erosion control.

It is thus possible to select a crop which is of greater economic value than Pangola. To this end, the work carried out by the Agronomy Department of this research station should be consulted (Younge and Moomaw, 1960; Takahashi, *et al.*, in preparation). Accounts have been given of crops that have successfully been grown on the stripmined area and the conditions under which establishment has been achieved. In general, heavy fertilizer applications are required, a factor which should be considered in computing the economics of erosion control. It is quite clear that simultaneously with providing erosion control, it is possible to substantially enhance the value of stripmined land in the area under consideration above that of the original, unmined land.

Table 6 has shown that surface soil replacement is not essential for erosion control on revegetated subsoil, even though table 8 has shown a minor effect on water runoff and table 9 on percentage ground cover. Surface soil replacement undoubtedly boosts crop production, but enhanced crop yields do not seem of significance in erosion control. A decision on surface soil replacement should thus be guided by the economics of the level of productivity of the stripmined land aimed at.

Statistical analysis of results

It had been contemplated by the reporters to carry out an analysis of correlations between rainfall and erosion, as has recently been done by Wischmeier, *et al.* (1958). However, it has not been possible to make short-term quantitative measurements. This is due, firstly, to the remoteness of the experimental area and, secondly, to the pattern of gradual soil displacement down-slope which, as mentioned, has escaped measurement. Therefore, a further analysis of the data does not seem warranted.

SUMMARY

Soil erosion and its possible control after stripmining was studied on an aluminous Humic Ferruginous Latosol during a 2-year period, when average rainfall conditions prevailed. The study was carried out in plots, 8 × 80 feet, to which various surface treatments were applied. Erosion was very small on surface-protected soil but 20 times as high on unprotected, compacted soil (compacted by the use of heavy machinery in stripping).

The study has been a model study of what happens beyond the plots and the similitude has not been a good one. On the unprotected soil this was caused by the plot boundary which probably caused soil losses measured to be in excess of those occurring beyond the plots. By contrast, soil losses

measured on the surface-protected soil did not properly represent soil movement on the plots as gradually displaced soil on a slope was caught by surface roughness and tended to escape measurement at the foot of the slope. Even though this soil displacement could be qualitatively proved, the magnitude was so small that it escaped measurement by marked metal stakes inserted on the plots for this purpose.

However, the results from the plot study in combination with observations made beyond the plots warrant a conclusion that the soil studied is of low erodibility. Nevertheless, erosion-protective measures are needed after stripmining.

Surface soil replacement on subsoil substantially reduced erosion because of (1) the high structural stability of the surface soil, (2) its high infiltration rate, and (3) the fact that the subsoil was scarified prior to surface soil replacement. A decision on whether or not to replace surface soil is guided by economics.

On the basis of infiltration measurements and erosion behavior, it has been concluded that subsoil should be scarified immediately after stripping to destroy compaction in the surface few inches of the subsoil exposed after mining.

Contour treatment as a general measure to control erosion is not recommended; drains tend to be rapidly choked as a result of the curious "self-mulching" property of the subsoil. Bagasse application is efficient but not very practical for general erosion control. However, a combination of bagasse application and simultaneous vegetation establishment may be considered.

Re-established vegetation affording a good ground cover gives satisfactory protection against erosion probably also during periods of unusually heavy rain, 10 inches or more per day, occurring once in 10 years or at longer intervals.

Field observations have led to some recommendations on provision for surface drainage on stripmined areas.

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